Systems Engineering
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Lecture-07
System Design Process

Good afternoon. Welcome to the course on systems engineering. Today we are going to talk about the systems design process and I am Dr. Deepu Philip from IIT Kanpur. So todays learning objectives we are discussing slightly about different version of the system design process used in non-defined industries, are they certain aspects are the same but there are some slight variations, we will discuss that.

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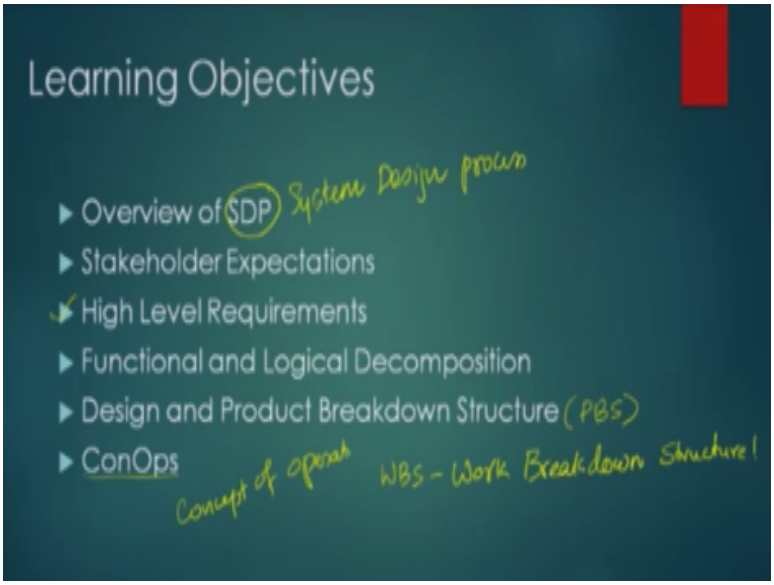

So we will talk about an overview of the system design process as DP, so as DP stands for system design process, okay and then we also talk about what is the stakeholder expectations? and who are stake holders? and how do we talk about expectations, we will also talk about high level requirements and why are they important in the system design process?

We also talk about how do we translate the high level requirements in to functional and logical decomposition and how this documents aids in the development of the system and then we will also talk about the design and the product breakdown structure, when we talk about the PBS, is

the product breakdown structure. Remember, in WBS stands for work break down structure, similarly PBS stands for product breakdown structure.

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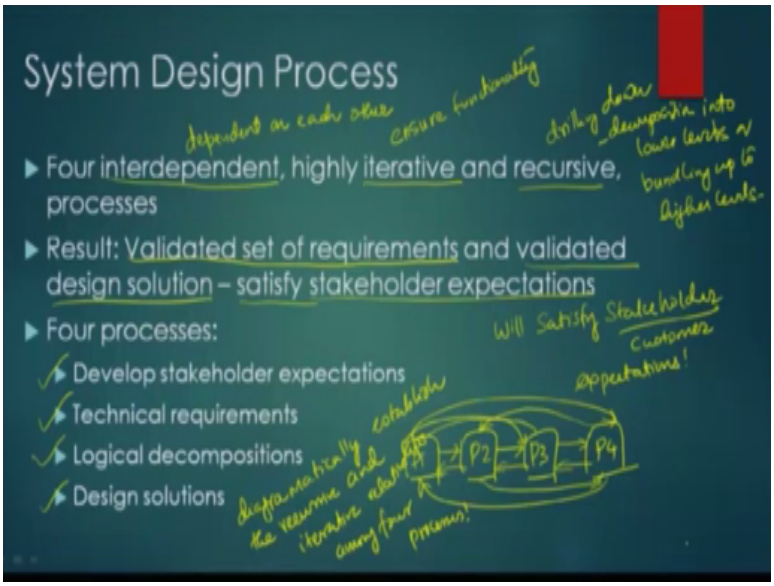

Then we finally we talk about stuff called CONOPS or concept of operations and what is it? And we will see this quickly. So the system design process in the simplest sense is a four independent highly iterative and recursive process. So there are four processes that are inter dependent, so that means they are dependent on each other thus the inter dependency, iterative; we already seen that iterative and recursive definitions, this is highly iterative.

So the same function applied over until a functionality is meet, this is to ensure, functionality, inter functionality out of these and the recursion on the other hand, this is a drilling down or decomposition into lower levels or bundling up to higher levels, okay and processes. So there are four inter dependent iterative and recursive processes and when you use these processes as a part of the DP, these process is result in, what you called as the validated set of requirements and validated design solutions.

It is validated set of requirements and validated design solution. What is it validated again is? the validation is always again a stakeholder expectations, so when you say it is validated, that means, it well satisfy, the idea is well satisfy stakeholder or just for the time being we use the word,

customer or synonymous, we will explain this latest expectations and so we talked about there are four processes, which are those processes?

The first process is about developed stakeholder expectation or we develop the stakeholder expectations from the input and then we establish the technical requirement and then we talk about the logical decompositions and the design solutions, these are the four processes so they are inter dependent, so if you make these processes as the four processes; p1, p2, p3, p4, so they are dependent like this, they are also dependent like this.

So all sort of dependencies does exist between them, okay and this at the end of the day will generate the design solutions that are required as part of this document, okay. So what we try to do today in the lecture is to diagrammatically establish the recursive and iterative relationships among the four processes. This is the aim of the lecture today, so in that way you all get a complete overview of what the system is about.

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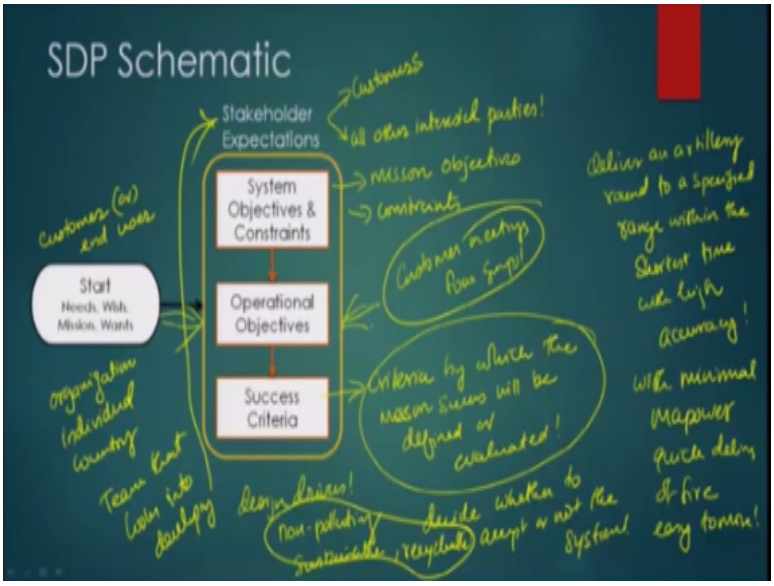

So we will start with the schematic and we will start with the simple way to look into the process, so the schematic always start with the needs, wish, missions, wants, etc so this is where the starting point, some where some needs have been established, so who established this, initially lets called this as the customer or end user, it could be anybody, it could be an organization, it could be an individual, so it could be an organization, it could be an individual.

It could be a country, or many things, okay, that can all be part of this, what we called as customer or the end user. So somewhere, somebody is specifies that there is a need or there is a wish, or there is a mission to be full filled or there is a want that is significant enough that a new system need to be developed, so this is a starting point. Once you have this, from there we generate, what we called as a stakeholder expectation.

So the term stakeholder is usually quite confusing in this regard and I will try to explain later, what it is? but the stakeholder in a broader sense is usually divided into two; one is the customer, the stakeholder can be thought about it as the customer and or customers and all other interested parties is the second part. So we will see how do we distinguish among customers and all other interested parties as part of this proposal.

So the stakeholder expectations gets derived out of the needs, mission, statements and wants that are created by the customer. Then it has three major parts in it. The first part is actually called as the system objectives and constraints, so sometimes people also called this as the mission objectives and constraints. So if you talk about a development of field artillery gun, the main objective is to deliver an artillery round to specified range within the shortest time with high accuracy.

If we say like something like this, this could be the objective of artillery round that we are trying to define, so the mission objectives and constraints to a large extent that comes from the needs, wish, and missions which are specified by the customer to begin with. The constraints would be in what are the limitations within which the system should operate, sometimes it could be like, it could be operate in a hilly terrain or it could be operate during rain.

It could operate during all weather conditions; this is all the part of the constraints aspect. The other aspect is the operational objectives, so the system objective might have been developed a system like this, but in the operational objective, it could be something like a we could add something like width, minimal, manpower, okay, quick delivery of fire, easy to move, something like this.

So this could be operational objectives, which on the top gets added by the customer into this process, okay and once you specified the operational objectives, you also have something called a criteria, success criteria. This is the criteria, by which the mission success will be defined or evaluated, this is the success criteria and this is important because at the end of the day, this is again as width which the customer will decide, whether to accept or not the system, okay.

Also something else also is there as a part of this, which is also called as the, some people called as the design drivers. This is also as part of this. This is like a philosophies that will drive the design process like somebody says that, I want to design an automobile, which is very eco-friendly or non- polluting or sustainable, okay or recyclable, something like this. So this could be other drivers that could be part of the design philosophy as such.

But all these things, what we talk about the stakeholder expectations gets derived, so a team literally work on this. So there is a team that looks into developing, developing what? All of these, okay and they develop it from the needs and wish and mission statements. So you require a lot of customer meetings, focus groups, there are so many tools available for this, so all these tools gets used to derive the stakeholder expectations.

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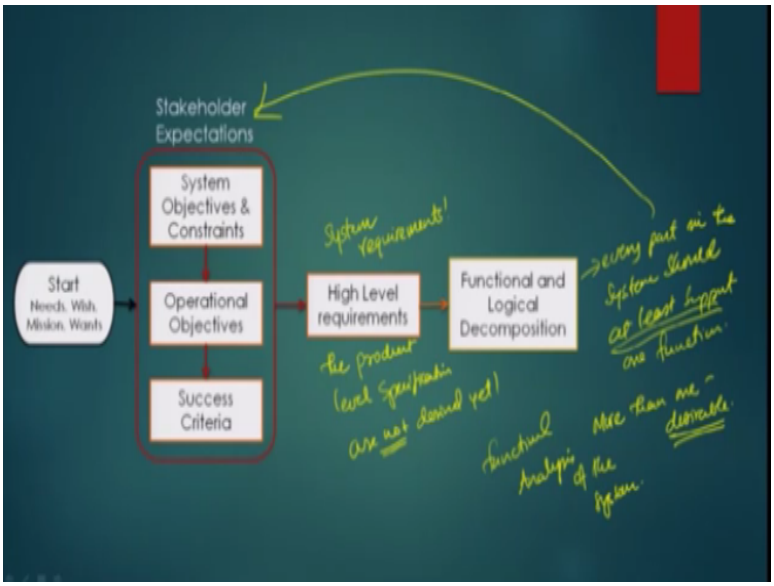

Once the stakeholder expectations have reached to some level of maturity, then from there this part we already seen, we derive something called as the high level requirements and from the high level requirements, that gives rise to what we call as the functional and logical decompositions. So we can, if you remember, this is one part of the four inter dependent iterative ad recursive process.

So the high level requirements is the requirements of the system, these are the system requirements and these are high level because we have not the product level specifications or not; they are not derived yet. So you are talking in the bigger terms, you are talking about high level requirements, you are not talking about one specificality of what type of firing pin you will be using in the artillery gun.

You might be just talking broadly about the gun that could deliver a round that a distance of 30km or 50km and like that and from there we talk about the functional and logical decompositions where we actually talk about what are the functions that the system will accomplish? and how logical, or logical way of accomplishing their functions. So there is a rhyme and reason how the functionality is included into the system.

As I said earlier that every part in the system should least support one function, which function? The function that was derived from the part of the stakeholder expectations. This was one of the rules that we have. It can support more than one function, that is nothing wrong in it, more than one, desirable, but least one is the important one, okay. So that allows you to, so this gives you the functional analysis of the system, okay.

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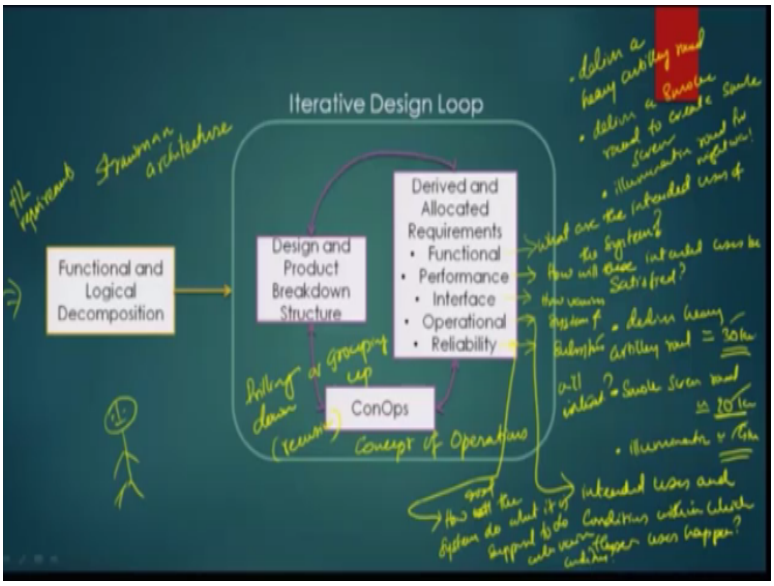

Once you reach this level, where you have a functional and logical decomposition, then we will look into the next sequence of how the operations gets, so all the things before we are kind of hiding and there is other stuff behind this but we are not discussing that at this point, we have already come with that discussion. From there, we get what we called as a iterative design loop, okay.

This iterative design loop to a large extent is a three step process which has, from the functional and logical decomposition, we derive the design and the product breakdown structure, the PBS and the design breakdown structure, so some of the designs that we would actually get out of this would be call as the Strawman architecture, the Strawman means like a very simplified diagram, so if somebody is asked to drive a human being, the Strawman diagram is this.

So this kind of gives that there is a face, there is some sensory organ, two hands and two legs, kind of a thing, so something like this, a broad idea of what the system design is all about, okay from there it also comes of something called as a CONOPS or something called as CONOPS stands for concept of operations. We will discuss what is the concept of operations literally related on the road?

A detailed definitions will be provided and within this process we also have the derived and located requirements. So the functional and logical decompositions, the step before this was the

high level requirements, HL requirements. So from there we added the functionality, from the functionality, we derive and located the requirements and this requirements include the functional requirements, the performance requirements, then the interface requirements, operation requirements, reliability requirements.

There are many other elite requirements, so the functional requirements to a large extent, will be like what are the intended uses of the system? This is the main question that is asked at the time of deriving the functional requirements. What are the main intended uses of the system? So if you are talking about the few artillery gun, it could be about deliver heavy artillery round, this could be one.

Another intended use would be deliver smoke round to create smoke screen and we could talk about even deriving something called as a illumination round for night war fire, something like this. So this could all be functional aspects of the system, okay the intended uses, it is not just delivering a heavy artillery round to inflict casualties, it could also deliver these two other thing as well, I mean, I am just using simple examples.

Now the performance on the other hand is how will these intended uses be satisfied? So one of the things that we might do is that, the system might perform or deliver heavy artillery round to a distance of approximately 30km and the small screen round, it might deliver only up to 20km, whereas illumination round, might only require up to 5km, so all these things are the performance, I mean just one, but there are many aspects of performance.

I am just giving as a one example how will the system intended, how will the system be satisfied those functional requirements? The interface is that the how various systems and sub systems will interact, this will be the interface part of the system design, then there is about operation, operations means what all conditions and what all aspects, so operations in a simple word to think about is intended uses and conditions within which those uses happen.

This would be the operational aspects of it and reliability in this case, we can talk about it has how will the, how good the system do what it is supposed to do under various conditions. So can

a deliver these, can we meet this performance parameters under rain, can it meet under snow, can it meet under dust storm, can it meet under heavy enemy fire, so all these aspects, how reliable is the system.

How even under these different conditions can system be capable of doing all these aspects that all these things, when you keep on doing this product, from once you have the answer to certain questions, then however design the product breakdown structures happens and then you will keep on growing, so this is where you might end up drilling down or grouping up, one of these the recursion might happen down in this area, okay.

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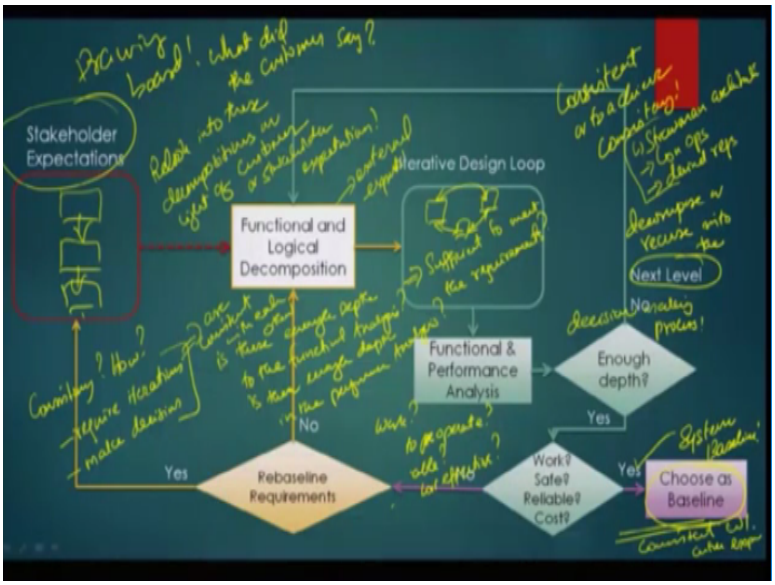

Once you have that then comes the, we will talk about this is the functional and logical decomposition and we talked about the iterative design loop and now we talk about how the iterative design loop in there; after that whatever the output we get out of the iterative design loop. We subject it to something called as the functional and the performance analysis. We tried to decide whether the system meets the functional requirements and it is also capable of doing the performance.

This could be an independent audit to some extent and it is usually a decision making process, so this is a decision making process, okay, and is there enough depth in realizing the functions, so the question is, is there enough depth to the functional analysis? Enough depth means sufficient

to meet the requirements. If the answer is yes, then you know, you can do it, if the answer is “no”, you can do something else, okay.

Similarly, is there enough depth in the performance analysis, this is also a second question and both questions are part of a decision making process, either answer is “no”, then you decompose or recuse into the next level. See you go the next level, you bring the whole thing, the system takes it down to the next level and again do the functional and logical decomposition and within which you start doing that three things we draw here, okay.

We do this, the design loops; the recursive and iterative process happens and the iterative design loop and you do again the functional and performance analysis, is there enough depth to the functional analysis, enough depth to the performance analysis, if the answer is “no”, you keep on drilling down. So the drilling down happens, the recursion also happens in the further level in this big loop outside that is shown to you.

If the answer is “yes” on the other hand, that is enough depth yes, it can, the functional and performance analysis is deep enough. Then you ask the series of question, the question is, the first thing is, will the system work? Then is the system safe to operate? operate and is the system reliable? Is it able to deliver reliable performance? Is the system caused effective? We can also ask questions like is the system within schedule of development.

This question can also be asked so if you have all these questions and asked this series of questions, the answer to all of them is, “yes”. All of these are true, it is correct, then choose that design, asked the baseline of the system. So here is you get your system baseline and if any of these questions, answer is “no”, then we have the question again, I will erase this, because I already written on the place, where it is not supposed to be, but anyway.

So you have some issues that some of these questions, is the system is not able to work, it is not safe to operate or it is not reliable, it is cause effective, then there is something wrong with your requirements, okay, whatever the requirements that you came out from the functional and logical

decompositions, the baseline requirements that you derived out of it. There is something that is not achievable, so you need to relook into that, you relook into that.

When do you relook this, how do you do? You relook into these decompositions on light of customer or stakeholder expectations. Here we are asking the question, is the wrong, we have to look into the functional and logical decomposition or the requirements need to be rebase line. So the rebase line requirements if it is, the answer is “no” to this question, then you end up to get the functional and logical decomposition.

If the answer is “yes”, the reason need for the rebase lining required. Then what you do? You go by to the stakeholder expectations, you are going back to the drawing board or the question is here is what did the customer saying? This aspect is looked into it and then from there again the drilling down through the stakeholder expectations, we had three things that part of these all those stuff, will continues as part of here.

Then you look into high level functions again you end up rebase lining requirements, because you had a rebase line requirements that you came up with were really not sufficient enough to come up with the baseline system design. So you need to relook into it. If you think that there is no need for a rebase lining, then you need to look harder at the functional and logical decomposition, what is gone wrong, we need to look into this.

Here you might end up taking the help of an external experts or something like that. Okay. So the aim of all these processes that we talked about, okay, so what as I said earlier is that, we talked about the strawman architecture concept of operations and derived requirements. So we came up with the requirements of the system, we ended up choosing the baseline. The most important aspect of doing all of these things is this one word consistent or to achieve consistency, okay.

Consistency among what, consistency among the strawman architecture, okay, so there is a strawman architecture, then there is a, what we call as a CONOPS and then there is a derived requirements, okay. All these three, there should be consistency among them and how do you

reach this consistency, how? How do you reach that? You require iterations, means you need to repeat the process and you need to make decisions.

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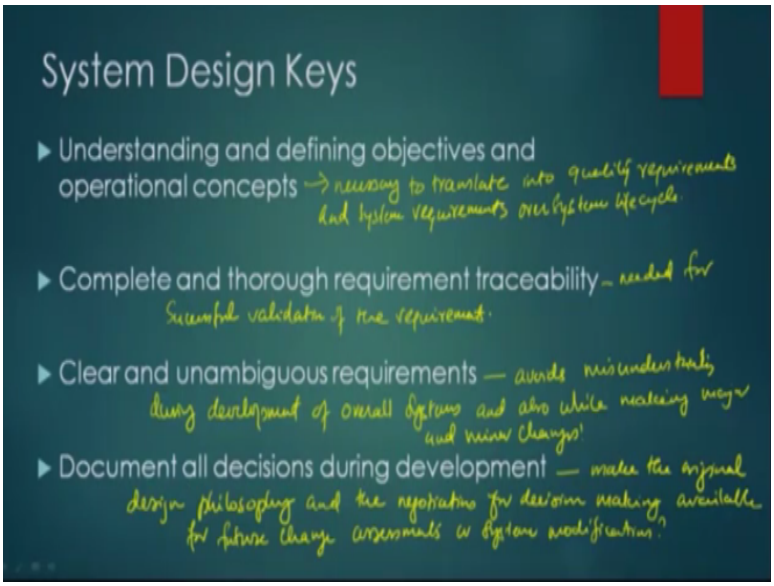

So at different juncture, you would make iterations and decisions in a way that, all these three are consistent with each other, okay. So the final base line that we choose, this is a consistent with customer expectations or stakeholder expectations, that is the baseline that is been chosen. So the as I said through earlier that a deciding team basically understands and defines the objectives and the operational concepts, so that basic key aspect of this, so you are talking about understanding and defining objectives and operational concepts.

So why do we need to do this? This is necessary, it's necessary to translate the objectives and operational concepts into quality requirements and system requirements over system life cycle, okay. The life cycle of the system, the quality and the system requirements, that is necessary to define objectives and operational concept of the system, that is what is coming out of one of the aspect of the system design, the key aspect of the system design, is a complete.

Second one is complete and thorough requirement traceability. Why do we need traceability? The traceability is needed for successful validation of the requirements, okay. So if the traceability is there, then you can say you can validate the requirements, came up with these functions can will

be traced and yes if it can be traced thus it is used to validated and it also ensures that clear and unambiguous requirements are also part of this.

The reason, the need for clear and unambiguous requirements is because of this, it avoids misunderstanding or misunderstanding during development of overall systems an also while making major and minor changes, okay. So if it is clear and unambiguous requirements, if that clear on then you can, there will be no confusion, no misunderstanding due to the system development and as well as there will widely are making minor or major changes.

You will be good to do that and another key aspect of a system design is to document all decisions during development. So why do you need to document all these decisions during the development. Because it helps you to make the original design philosophy, original design philosophy and the negotiations for decision making or negotiations during the decision making available for, for what? For future change assessments or system modifications.

So one of the decision lets we talk about the artillery equipment that we are talking about as an example. One of the decision that was made at this point was, whether the artillery barrel should be smooth bore or should be rifled. So there was, the strata between the smooth bore and riffled ones, so at some point of time, let us say that the group or the technical experts or the system team decided to use riffled barrel, then why the decision was made?

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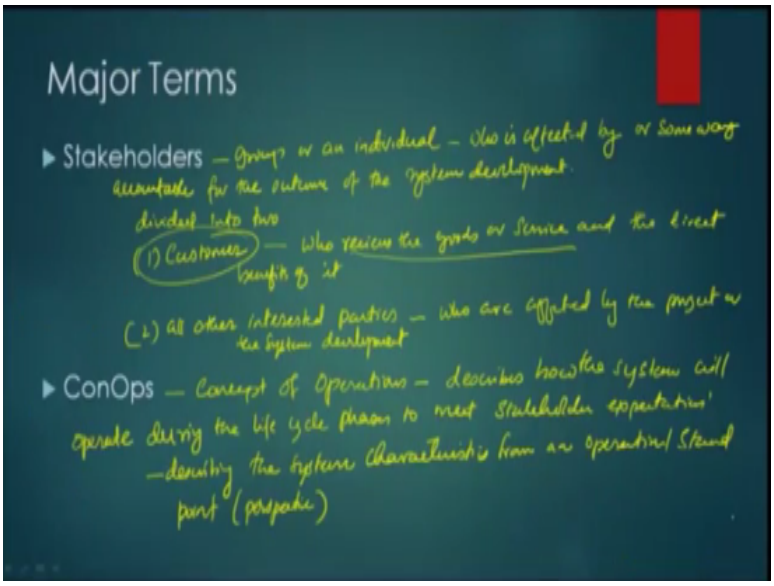

What was the motivation factors behind that decision, then you need to be clearly made available, because in the future, either you want make changes to something like this, then they need to know, what drove the design? What drove the people to get into that particular riffled barrel design and as I said earlier that there are two major terms that we need to discuss or defined as part of this. One is called as a stakeholders, and the other is the CONOPS.

So we will define these terms in light of what we saw all this kind of or all those aspects of the SDP, the modified as DP or the modern as DP, what you want to call it? Who is the stakeholder? A stakeholder can be a group or an individual, I apologize for my spellings, you can come up with a good correct spelling, so group work or an individual and what are the characteristics of them?

Who is affected by or some way accountable for the outcome of the system development. So it is a group or an individual, either they are affected by the system as such or somewhere they are responsible for the outcome, the system, that the final system that is derived. Stakeholders are typically divided into two, the number one is the customer, and number two is the all other interested parties, okay.

Who is the customer? The customer is the one who receives the goods or service and the direct benefits of, so the customer is the one who receives the good or service and also the direct

benefits associated with it, that is the customer. So customer is the stakeholder and all other interested parties, okay. These are the ones who are affected by the project or the system development.

This would involve manufacturers, the subcontractors, the financing agencies, the engineers that are part of this, the design validators, the technical experts who are all part of the development of the system. So the stakeholder, the customer and as well as the people who are participating in full filling the customer needs, both falls under the term called stakeholders and in most of the time, the term customer is used in synonymous to the stakeholders.

Whereas the other people are, the other interested parties are forms the very negligible reference to the word phrase stakeholders. The CONOPS are the, is the short term of something called concept of operations. What it is that? It is the document or something that describes how this system will operate during the life cycle phases to meet stakeholder expectations. So how will the system operate, how will the system work?

So in a way it is actually describing the system characteristics from an operational standpoint or an operational standpoint or you can think about this operational perspective, okay. So the CONOPS to a large describes how the system will operate during the lifecycle phases to make stakeholder expectations and you use the stakeholders or the customer and as well as other interested parties to derive what we called as the stakeholder expectations.

In that process what we saw earlier in the previous slide that this all loop, this system design process loop as DP loop is done to create what we call as a consistent baseline system design which actually needs the expectations of the stakeholder. With this today's lecture, we will conclude and we will start into drilling down of how the stakeholder expectations or the tools available to do that.

Then we will talk about how the high level requirements in the functional decomposition happens and then we talk about how do we synthesize the design using a few examples and few

tools and then we will conclude by how the system design process or how the system actually gets to realized. Thank you very much.